

Using Contact-Specific Surface Area Estimates in Exposure Models

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ABSTRACT

The objectives of this work are to demonstrate methods for the collection and incorporation of contact-specific surface area measurements in dermal exposure assessments and illustrate the potential difference in resulting dermal and non-dietary ingestion estimates using this type of surface area data. Continuing the work of Stanford's Exposure Research Group, categorical surface area data contained in children's sequential microlevel activity patterns were converted into quantitative coordinates, which in turn provided a foundation to map data on the skin surface. Programs were constructed to establish an accounting system of spatial coordinates, governed by categorical surface area data, to map exposure estimates or activity statistics on the skin. An illustrative example is provided that estimates the spatial variability of chlorpyrifos on the palm of a hand using contact-specific surface area data. Results show a maximum value of 14.6 ng on the fingertips and no chemical exposure along the edges of the fingers and in the center of the palm. The methodologies presented could result in more realistic estimates of concentration gradients across the skin, better representations of dermal exposure due to multiple contacts, improved approximations of nondietary ingestion, and enhanced models of dermal dose.

Key Words: dermal exposure, nondietary ingestion exposure, skin surface area, dermal contact, microlevel activity patterns, modeling

INTRODUCTION

Information on exposed skin surface area is requisite in models estimating dermal and nondietary exposure to contaminants. The incorporation of surface area data

in model equations, however, varies and is often insufficient to account for spatial variation of contaminants on the skin. Early models used conservative estimates (e.g., 100% surface area of exposed body part), while contemporary mechanistic models use randomly selected surface area fractions from a range of values. Both methodologies, however, are utilized with little or no empirical skin contact surface area data. Furthermore, a uniform distribution of contaminant mass on skin is typically assumed, resulting in spatially averaged exposure estimates. This article illustrates potential methods and algorithms to incorporate newly collected contact-specific surface area data, specifically for hand-to-object contacts, into mechanistic models of dermal and nondietary ingestion exposure.

BACKGROUND

Body surface area is one of the more difficult dermal exposure parameters to measure. Direct methods of measurement include coating, surface integration, and triangulation. Coating methods begin by using paper, paint, plaster, or other material to cover the skin and proceed by flattening and measuring the coating material or using an established calibration to estimate surface area. Direct surface integration uses specialized planimeters on human skin to measure surface area. Triangulation involves marking off triangles and trapezoids on the body and calculating the surface area of each shape by their linear dimensions. Indirect methods have historically included estimating surface area from two-dimensional photographs of silhouettes of body parts (photographic methods), using lengths and circumferences of body parts to estimate surface area as cylinders or truncated cones (linear methods), and utilizing developed formulas relating surface area to height and/or weight (Boyd 1935).

Aside from the extensive review of methods and collection of measurements by Boyd (1935), few studies have had an impact on expanding surface area data. Additional direct measurements include the use of linear methods by Haycock *et al.* (1978), coating and surface integration by Nwoye (1989), and three-dimensional scanning by Jones *et al.* (1994) and Tikuisis *et al.* (2001). The majority of literature, particularly that geared toward the medical field, has focused on indirect methods—specifically the reformulation of equations using different subsets of data. Sendroy *et al.* (1954), for instance, used previously collected direct and indirect estimates to establish a relationship between surface area and the sum of an individual's height and weight (as opposed to the conventional product of height and weight). Gehan and George (1970) used data from Boyd (1935) to simplify the calculation of surface area, improve the accuracy of estimates, and make the results applicable to a larger population. Current (1998) similarly used a subset of data reviewed by Boyd (1935) to create a simplified equation aimed at improving body surface area estimates of infants and children. In spite of these supposed improved efforts, arguably the most widely used method to estimate body surface area is still an equation determined by DuBois and DuBois (1915, 1916) based on only nine direct measurements (Haycock *et al.* 1978; Shuter and Aslani 2000).

CONTACT-SPECIFIC SURFACE AREA

Although total body surface area is important in modeling dermal exposure, more detailed data on the specific portions of skin contacting contaminated media or objects are necessary in complex systems modeling both dermal and nondietary ingestion exposure. While those modeling exposure typically do not consider detailed surface area estimates, scientists studying dermal transfer factors, such as residue transfer parameters and particle adherence to skin, are slowly recognizing the need to consider contact-specific surface area.

Lu and Fenske (1999), while comparing methods to determine transfer of chlorpyrifos from residential surfaces, estimated dermal contact areas by collecting handprints using finger paints and calculating hand width and palm area. Using a video imaging system, Brouwer *et al.* (1999) captured the adherence of a fluorescent whitening powder to the skin to examine contact-specific surface area. Rodes *et al.* (2001) used two methods to explore contacted area. In one method, images of hand presses were obtained by pressing against the glass plate of a copying machine. The copied images of contact-specific areas were cut out, weighed, and then compared with an area of paper with known weight. A second method involved taking photographs of particles remaining on dust-laden contact plates after a palm press. Images were printed and contact areas were again cut, weighed, and compared to a calibrated area of paper.

REFINED CONTACT-SPECIFIC SURFACE AREA

In early 1999, Naylor and colleagues (Naylor *et al.*, 2000) began to develop methods to collect information regarding children's contact-specific surface area. This project began with the collection of sequential microlevel activities (i.e., location, object type contacted, duration of contact) using videography techniques, standard protocols, and the Virtual Timing Device to translate video footage to text files representing activities. The study population included 20 children, ranging from 1 to 6 years of age, who lived in the San Francisco Bay Area (Leckie *et al.* 2000).

Unlike previous studies using videography methods, the videotapes were reprocessed to collect qualitative contact-specific surface area information. For hand-to-object and object-to-mouth contacts, a set of possible hand configurations was developed based upon visual assessment of children's videotaped activities and experience translating videotapes to activity files. General hand configuration categories included grips, front finger contacts, front hand contacts, side hand contacts, back finger contacts, back hand contacts, and immersions. The majority of these general categories also contained subcategories to compose a total of 20 hand configurations. Table 1 shows all hand configurations with a brief description. While not emphasized in this article, categories similar to those describing hand-to-object contacts were developed to translate object-to-mouth contacts. Surface area categories for mouth behavior are described in Tables 2 and 3.

Table 1. Hand configuration categories, description, and code

Hand configuration	Description of contact	Code
Grips	Thumb opposes fingers during contact event	
Pinch	Fingertips grip object without palm contact	PNG
Closed hand	Hand grips smaller diameter tube with fingers overlapping thumb	CHG
Open hand	Hand grips larger diameter tube with no overlapping fingers	OHG
Front finger contacts	Only front fingers contact object and thumb does not oppose fingers	
Front partial fingers	Less than half of fingers	PFF
Full front fingers	More than half of fingers, but none of the front palm	FFF
Front hand contacts	Only front palm surface (and possibly fingers) contacts object	
Partial front palm with fingers	Full front fingers and less than half of front palm area	PPF
Partial front palm without fingers	Less than half of front palm area and no fingers	PPO
Full front palm with fingers	Full front fingers and more than half of palm area	FPF
Full front palm without fingers	More than half of front palm area and no fingers	FPO
Side hand contacts	Side of hand contacts object	SHC
Back finger contacts	Only back fingers contact object	
Back partial fingers	Less than half of back fingers	BPF
Back full fingers	More than half of back fingers, but no palm area	BFF
Back hand contacts	Only back palm surface and possibly back fingers contact object	
Partial back palm with fingers	Full fingers and less than half of back palm area	PBF
Partial back palm without fingers	less than half of back palm and no fingers	PBO
Full back palm with fingers	full fingers and more than half of back palm area	FBF
Full back palm without fingers	More than half of back palm area but no fingers	FBP
Immersion contacts	Front, back, and side of fingers and/or palm area contact object	
Partial finger immersion	Less than half of fingers are immersed	PFI
Full finger immersion	More than half of fingers, but none of palm area	FFI
Partial palm with finger immersion	Full fingers and less than half of palm area	PPI
Full hand immersion	Full fingers and full palm	FHI

Note: Adapted from Leckie *et al.* 2000.

Table 2. Hand mouthing categories, description, and code

Hand-to-mouth contact categories	Description of contact	Code
Outside mouth	Fingers and/or hand touching lips, no immersion inside mouth	OMF
Partial fingers	Less than half of the fingers immersed in the mouth	PFF
Full fingers	More than half of the fingers, but no palm area, immersed in the mouth	FFF
Partial palm with fingers	Fingers and part of the palm area immersed in the mouth	PWF
Partial palm without fingers	Part of the palm, but none of the fingers, immersed	POF

Note: Adapted from Leckie *et al.* 2000.

To amend the output of sequential contacts from the Virtual Timing Device, the existing text files of activities were imported into an Excel template. The template, shown in Figure 1, facilitated the time-consuming endeavor of recording, for each hand-to-object contact, a more specific description of the object, the number of fingers involved in the contact, and the most relevant configuration category. The template included a series of conditional statements allowing the translator to convert the marked Excel worksheet into a usable text file for subsequent analysis and modeling of dermal and nondietary exposure. Figure 2 depicts a portion of a resulting activity file. Columns amending original hand-to-object activity files include

Table 3. Object mouthing categories, description, and code

Object-to-mouth contact categories	Description of contact	Code
Outside mouth	Object is touching lips but not immersed in the mouth	
Outside mouth, partial lips	Less than half of the lips are contacting the object	OPO
Outside mouth, full lips	More than half of the lips are contacting the object	OLO
Eating utensils	Usage of the object can be grouped as an eating utensil	
Spoon/fork	Common usage	SFO
Cup/bottle/can	Common usage	CBO
Drinking straw	Common usage	DSO
Bites	Object is immersed in the mouth and is not an eating utensil	
Small	Mouth area is only partially extended to contact the object	SBO
Large	Mouth area is fully extended to contact object	LBO

Note: Adapted from Leckie *et al.* 2000.

Figure 1. Screen capture showing an activity pattern file (in columns A through E) and the template for indicating contact-specific surface area data.

Contact-Specific Surface Area Estimates

location	object	duration	SAcat	numfing
Yard	Hard_Toy	6	OHG	5
Yard	Nothing	1	None	NA
Patio	Hard_Toy	16	FPF	5
Yard	Nothing	11	None	NA
Yard	Clothes	2	PFF	3
Yard	Nothing	1	None	NA
Yard	Vegetation	5	PNG	3
Yard	Nothing	10	None	NA
Street/Sidewalk	Nothing	12	None	NA
Yard	Nothing	3	None	NA

Figure 2. Illustration of a resulting text file with both activity data and contact-specific surface area data.

SAcat, designating a surface area code or category, and *numfing*, indicating the number of fingers utilized in the contact.

Additional work by Naylor *et al.* (2000) was aimed at quantifying the fractional surface area for each hand-to-object contact. Small-scale experimental work was carried out using traces of children's hands. The surface area enclosed by the hand trace was captured using a planimeter and certain linear dimensions were recorded with a standard ruler. Using geometric approximations (e.g., assuming fingers are shaped like cylinders), total hand surface area, as well as the surface area of each grip or contact type, was estimated. The fraction of each contact type of the total hand surface area was then computed. The fractional surface areas were then further reduced to 11 clusters (A–K) representing similar quantitative fractions (see Table 4). Thus, these clusters indicate that simulations for estimating dermal and nondietary ingestion exposure can be refined by using more specific and accurate surface area data.

Kitwana *et al.* (2003), building upon the work of Naylor *et al.* (2000), used adult handprints representing various hand configurations, rather than geometric approximations from hand traces, to estimate contact-specific surface area. Prints were collected by applying a layer of paint on individuals' hands before having them grip various objects (e.g., books, cylindrical objects) and contact surfaces (e.g., flat surface with fingertips) covered with paper. Prints were scanned into digital images and imported to AutoDesk® Architectural Desktop software to estimate the painted surface area. Total hand surface area was determined with a geometric approximation using the perimeter and surface area of hand traces and heights of knuckles. The

Table 4. Data for fraction of total hand surface area and clusters of hand configurations

Hand configuration	Code	Cluster	Lower bound	Upper bound
Side hand contact	SHC	A	0.02	0.04
Pinch	PNG	B	0.04	0.08
Front partial fingers	PFF	B	0.04	0.08
Back partial fingers	BPF	B	0.04	0.08
Partial front palm without fingers	PPO	C	0.07	0.10
Partial back palm without fingers	PBO	C	0.07	0.10
Full front fingers	FFF	D	0.09	0.16
Back full fingers	BFF	D	0.09	0.16
Full front palm without fingers	FPO	E	0.13	0.19
Full back palm without fingers	FBP	E	0.13	0.19
Partial front palm with fingers	PPF	F	0.16	0.25
Partial back palm with fingers	PBF	F	0.16	0.25
Closed hand grip	CHG	G	0.23	0.35
Open hand grip	OHG	G	0.23	0.35
Full front palm with fingers	FPF	G	0.23	0.35
Full back palm with fingers	FBF	G	0.23	0.35
Partial finger immersion	PFI	H	0.25	0.31
Full finger immersion	FFI	I	0.51	0.61
Partial palm with finger immersion	PPI	J	0.75	0.81
Full hand immersion	FHI	K	1.00	1.00

Note. Adapted from Naylor *et al.* 2000.

contact-specific surface areas were then normalized to the total hand surface area. Estimates revealed a relatively narrow range of contact-specific surface areas when compared to those used in previous dermal exposure models and smaller fractions compared to analogous hand configuration categories in Leckie *et al.* (2000) and Naylor *et al.* (2000).

CONSIDERATION OF SPATIAL CHARACTERISTICS

While employing the improved quantification and more precise range of fractions of surface area in dermal models leads to more realistic simulations, the results are nevertheless exposure estimates uniformly and spatially averaged over the entire hand. Spatial information insinuated in different grips and hand contacts is lost. It may then be important to not only specify a more accurate range of surface area data, but to also use knowledge of the spatial characteristics of the contacts. Considering such characteristics may be especially beneficial in nondietary ingestion exposure, where only portions of the hand come in contact with the mouth, and in accurately calculating dermal dose due to concentration gradients.

As an example, the amended microlevel activity data, for 20 children in 6 age groups, were analyzed to examine the average frequency (contacts per hour) for each surface area category. Table 5 details the average frequency of surface area

Table 5. Average frequency (contacts/hour) for 1 year olds by configuration

Right-hand contacts		Left-hand contacts		Mouth contacts	
None	268.0	None	260.0	None	97.6
FPF	88.0	FPF	100.5	PFF	13.3
OHG	61.2	OHG	55.1	Food	7.2
CHG	28.6	CHG	26.4	FFF	6.8
PPF	27.2	PPF	24.1	OMF	4.2
PNG	18.1	PNG	17.4	OLO	3.8
PFF	18.0	PFF	12.3	OPO	2.5
PFI	6.7	FFI	5.8	CBO	1.1
FFI	2.8	PFI	1.9	SBO	0.7
PBF	2.5	FPF	1.9	POF	0.5
SHC	2.2	FFF	1.5	LBO	0.1
BPF	2.0	PBF	1.2		
FFF	1.6	BPF	1.1		
FBF	1.6	SHC	0.7		
PPO	0.7	PPO	0.3		
FPO	0.7	FBO	0.3		
PBO	0.5	FHI	0.2		
PPI	0.2	BFF	0.1		
BFF	0.1	PBO	0.1		

categories for left hand, right hand, and mouth contacts of four one-year-olds. Categories in each table are listed in order from greatest to fewest occurrences. The analysis for hand contacts revealed a higher frequency of grips (PNG, CHG, OHG) and contact with the full front palm with fingers (FPF), front partial fingers (PFF), and partial front palm with fingers (PPF), when compared to all other object contact types.

If it is assumed that contaminants accumulate on portions of the hand with the greatest number of contacts, then the front fingers, according to the sequential activity patterns, should have the highest level of contamination compared to the rest of the hand surface area. Furthermore, analysis of the data for mouth contacts indicates that among the most frequent objects inserted into the mouth are the fingers (PFF, FFF). Current dermal exposure models, however, estimate the mass of contaminant per unit surface area of the hand after each macroactivity or contact event. This methodology for calculating exposure, in effect, dilutes the contaminant over the entire body part. This dilution then potentially underestimates the amount of contaminant transferred from the hand to the mouth in nondietary ingestion exposures.

In considering spatial characteristics, then, the method developed here is an accounting system of spatial coordinates, governed by categorical surface area data, on the skin. These coordinates are then utilized in dermal exposure models to estimate the mass of contaminants on certain portions of the skin resulting from

dermal contacts. This allows for contaminant distributions that are uniform across coordinates that represent a specific contact or grip, rather than the entire hand surface area.

METHODOLOGY

Methods to collect hand traces and contact-specific prints used by Naylor *et al.* (2000) and Kitwana *et al.* (2003) were modified slightly with the goal of obtaining spatial consistency between all grips and contacts. Because of this desire for consistency, only 1 adult male was used to create the prints and a single hand trace was used as a template for all hand configurations. Rather than applying paints directly onto the skin, tempera poster paint, mixed with a few drops of dishwashing soap to aid spreading, was applied to surfaces (e.g., various containers representing cylinders, nonabsorbent paper plates representing flat surfaces). These surfaces were contacted according to the hand configurations described in Leckie *et al.* (2000)—transferring paint to the hand—and then the hand was pressed onto the hand trace template.

The hand trace template and all prints were scanned into digital images and imported to Adobe® Photoshop® software. This software was chosen because of certain features that allow for semitransparent layering of images and the determination of relative coordinates of points on an image. Key perimeter coordinates were obtained for a hand trace. Each scanned print was then converted to a semitransparent image and layered over this original hand trace. Since each print transferred paint to a hand trace template, the original hand trace and the trace template containing the print could be aligned. The perimeter coordinates for each hand configuration print were then recorded.

Perimeter coordinates were imported to S-PLUS® 6.0 software and used in a series of custom functions to represent contact-specific surface area on the front and back of the hand (i.e., palm and fingers). Preliminary functions transformed relative coordinates from Photoshop® to a more suitable S-PLUS® coordinate system, while subsequent code utilized the perimeter points of the trace and prints to capture enclosed surface area coordinates and map them onto a standard grid. The data were calibrated so that each point on this grid or matrix represented 1 mm². Coordinates for each contact-specific surface area category were stored in a list, separating palm from finger coordinates, if applicable. Supplementary programs were created to extract coordinates from the list based on the hand configuration codes (e.g., PNG, PFF) in sequential activity pattern files or from summarized frequency data. Given a numerical value (e.g., mass of contaminant or number of occurrences) and a surface area configuration code, the program then applies the numerical value to the specific matrix cells given by the configuration coordinates. Since the number of fingers used in certain contacts may vary, the extraction function randomly samples the number of fingers corresponding to the *numfing* data and uses these coordinates to map numerical data (see Figures 3 and 4).

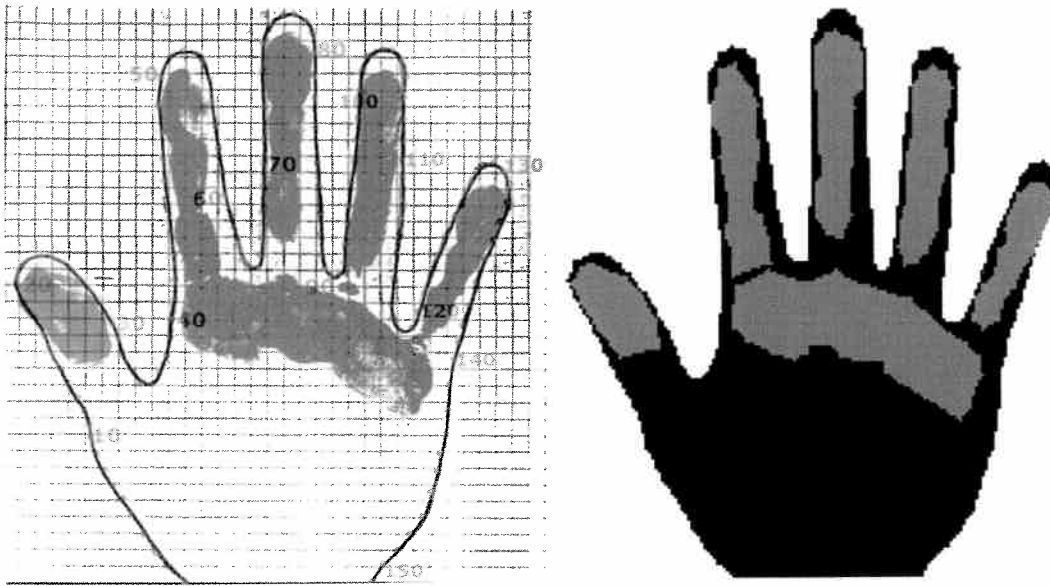


Figure 3. On the left is a layered image showing a hand trace and print resulting from a contact with part of the palm and all fingers (PPF). The right image displays the graphed coordinates, captured with a series of specialized programs, representing the PPF contact.

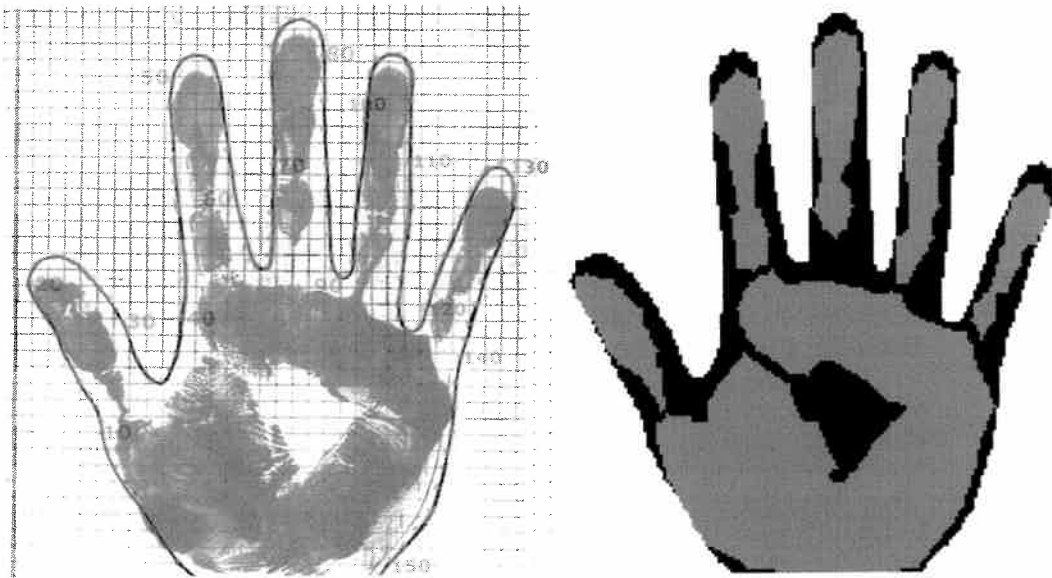


Figure 4. On the left is a layered image displaying a hand trace and print resulting from a contact with the full front palm and fingers (FPF). On the right is the digitized image representing the FPF contact in the developed algorithms.

Table 6. Comparison of fractional surface area estimates

Hand configuration	Naylor <i>et al.</i> 2000			Kitwana <i>et al.</i> 2003			This study Point
	Code	Min	Max	Code	Min	Max	
Side hand contact	SHC	0.02	0.04	SH	0.02	0.06	0.02
Pinch	PNG	0.04	0.08	PP	0.01	0.04	0.02
Front partial fingers	PFF	0.04	0.08	PFF	0.01	0.05	0.02
Partial front palm without fingers	PPO	0.07	0.10				0.07
Full front fingers	FFF	0.09	0.16				0.07
Full front palm without fingers	FPO	0.13	0.19				0.13
Partial front palm with fingers	PPF	0.16	0.25				0.10
Closed hand grip	CHG	0.23	0.35	SG	0.09	0.17	0.10
Open hand grip	OHG	0.23	0.35	LG	0.10	0.20	0.12
Full front palm with fingers	FPP	0.23	0.35	FHP	0.15	0.24	0.22

RESULTS

Although fractional areas are not the focus of this article, the contact surface area data were normalized to an estimate of the total hand surface area. Total hand surface area was computed by summing the surface area of the front and back of the hand (estimated by the surface area of a hand trace) and the area along the edges of the hand (estimated by the perimeter of the trace and the average height of the knuckles), similar to the method employed by Kitwana *et al.* (2003). As shown in Table 6, the fractional contact-specific surface areas for this study compare favorably to those gathered for analogous categories by Kitwana *et al.* (2003). All point values for this study are also below or at the lower limit of the estimates by Naylor *et al.* (2000).

Two examples of using contact-specific surface area data and the custom functions and algorithms are demonstrated. The first of these portrays a graphical representation of summarized categorical surface area data. Table 7 shows count data for 7 grip types collected from the activity file of a 1-year-old female. Utilizing the spatial coordinates, the same data are displayed in Figure 5. This figure then illustrates

Table 7. Count data for hand configurations within an example activity file

Hand configuration	Code	Count
Closed hand grip	CHG	36
Full front fingers	FFF	2
Full palm without fingers	FPO	2
Open hand grip	OHG	143
Front partial fingers	PFF	20
Pinch grip	PNG	32
Partial palm with fingers	PPF	35

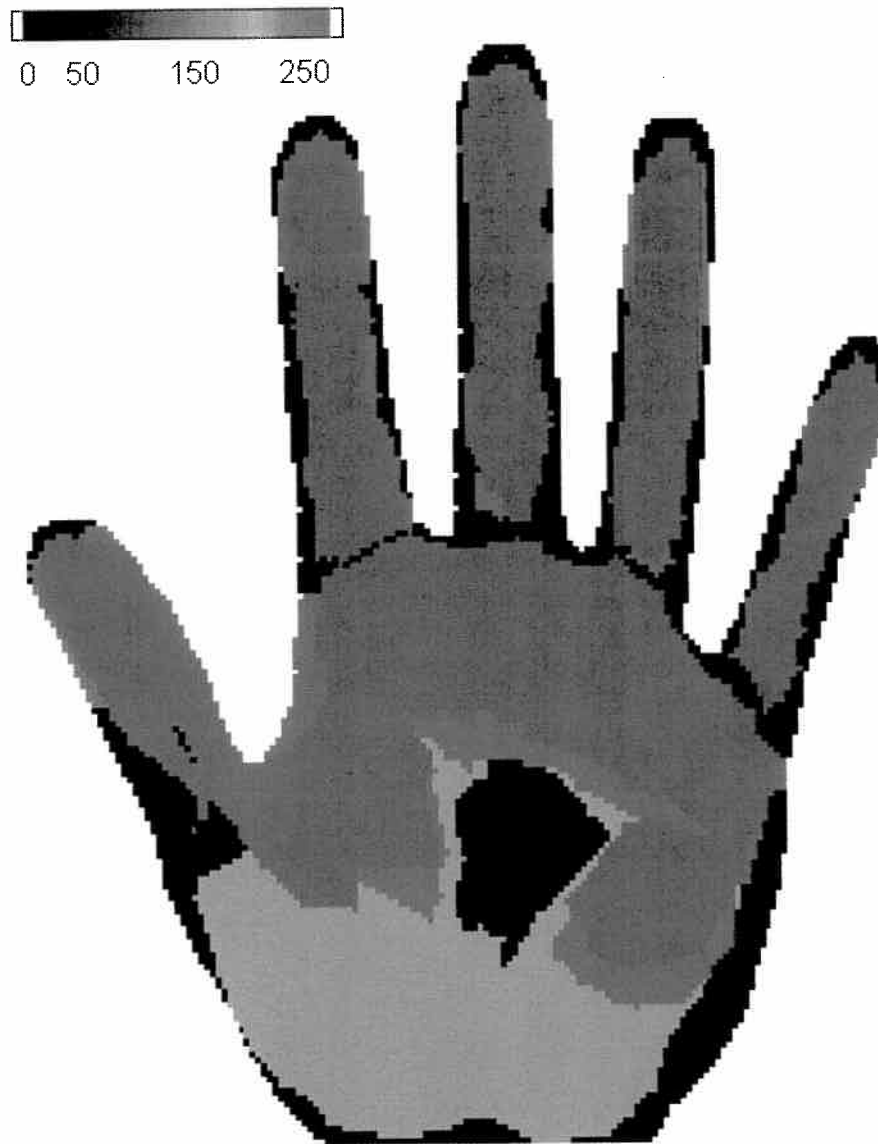


Figure 5. Using the captured coordinates from each grip and contact type, the image displays the cumulative count data from Table 7.

an alternative and more informative representation of grip types, without requiring synthesis of overlapping surface area codes or even knowledge of qualitative hand configurations. Although OHG (open hand grip) is the most frequently occurring surface area category with 143 contacts, Figure 5 values reach above 250 contacts. This discrepancy is due to the algorithm summing the individual cells of data each representing 1 mm^2 of the surface. The most frequently contacted areas—the fingers and upper palm—are then the combination of OHG, CHG, PPF, and PFF hand configurations.



Figure 6. Contact-specific data was incorporated into a dermal exposure model. The image plot represents the nonuniform cumulative mass of chlorpyrifos on the skin surface.

Spatial characteristics of contacts may also contribute to more specific estimates of contaminant mass over the skin surface. Figure 6 is an illustrative example showing the result of combining estimates of chlorpyrifos exposure from a dermal exposure model and the established coordinates of contact-specific surface areas. For each hand contact in a sequence of microlevel activities, a value for a surface concentration and residue transfer efficiency are selected from representative distributions. Values for surface concentrations, in ng/cm^2 , are represented by a lognormal distribution

with a geometric mean of 0.61 and geometric standard deviation of 2.54 (Zartarian *et al.* 2000). The unitless transfer efficiency is represented as a uniform distribution from 0.03 to 8.2% (Zartarian *et al.* 2000). The product of these two random values estimates the initial mass transferred for a given contact. The difference between this product and 1% of the initial mass, accounting for dermal absorption (Pang *et al.* 2002), estimates the final mass on a portion of the palm given by the contact-specific surface area data. While this is not a validated exposure estimate, it is similar to other dermal exposure models, and it provides an adequate illustration of the use of the unique surface area data.

Averaging the variable mass over the entire area of the palm and fingers reveals an estimate of less than 6 ng or approximately 0.04 ng/cm². Figure 6, however, displays the mass of chlorpyrifos on the skin as nonuniform values. An additional function was created to allow a user to interactively click on two points, defining a line segment across the figure. Exposure estimates stored in the underlying matrix and representing the segment are extracted. Values along the line segment AB, for example, range from 0 to 14 ng, and are displayed in Figure 7.

This nonuniform loading also has implications for nondietary ingestion exposure estimates—specifically that portion due to hand-to-mouth contacts. Assuming the tips of fingers are most frequently inserted into the mouth compared to other portions of the hand, averaging over the entire surface area of the hand may dilute the actual contaminant mass and underestimate nondietary ingestion exposure.

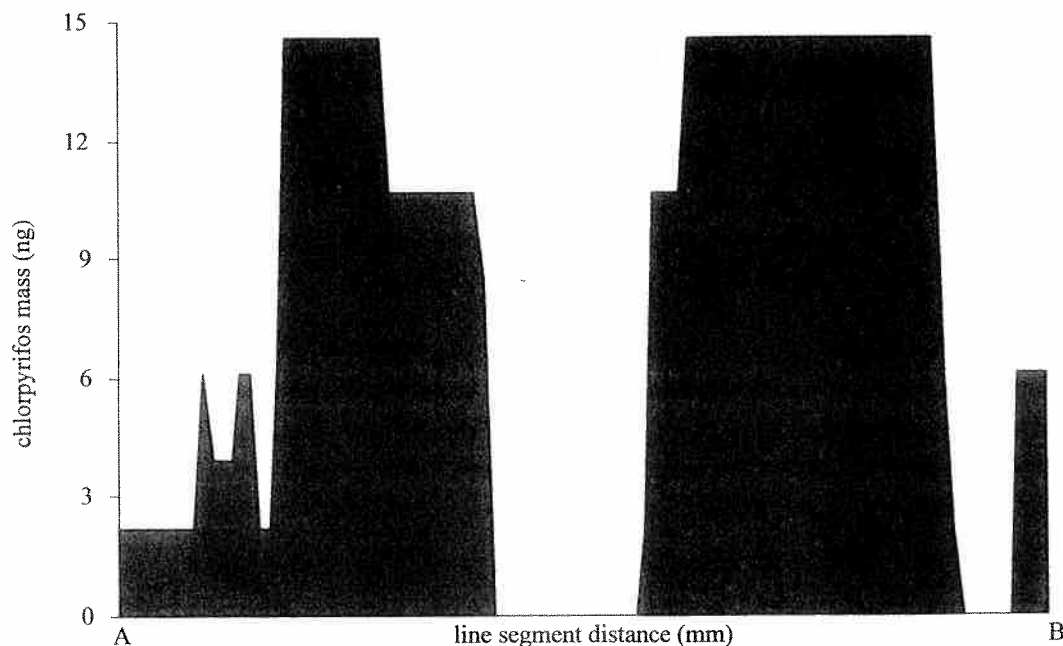


Figure 7. Data along the line segment AB of Figure 6 is extracted and plotted to illustrate nonuniform loading of mass across the skin surface resulting from the incorporation of contact-specific surface area data in a dermal exposure model.

Extracting modeled chlorpyrifos estimates corresponding to the tips of the fingers (above the first knuckle) reveals dermal exposures of 0.51, 0.95, 0.82, 0.85, and 0.65 ng/cm² for the thumb, pointer, middle, ring, and pinky finger, respectively. These values are at a minimum 12 times greater than the diluted average over the entire hand surface area

CONCLUSIONS

While the methods to collect contact-specific surface area data have limitations (e.g., number of grip types, precision of surface area measurements), they are an improvement over current approaches for determining and representing skin surface area. Studies by Leckie *et al.* (2000), Naylor *et al.* (2000), and Kitwana *et al.* (2003) have illustrated relatively simple methods to capture these data, and innovative models have used these refined quantitative data, along with sequential contact behavior, to model dermal and nondietary exposure (Canales 2003).

This work has taken the incorporation of surface area data in exposure models one step further than previous studies by attempting to account for spatial characteristics of qualitative hand configurations. The methodologies for recording these characteristics and algorithms for utilizing these data in models could result in more realistic estimates of concentration gradients across the skin and better representations of dermal exposure due to multiple contacts. Such considerations are important in nondietary exposure, where hand-to-mouth contacts are an essential component, and in accurately representing mass transfer to the skin and dermal dose.

Although the feasibility of these techniques to incorporate contact-specific surface areas in models may be in question, these methodologies could serve as a learning tool. At a minimum, the current results bring to light issues regarding the default method of modeling exposures—averaging the mass of transferred contaminant over the entire surface area of the skin and the potential nonuniform loading across the hand surface area. Coupled with experimental work, the issues of contact pressure could be investigated and the implication of utilizing spatially averaged dermal exposure measurements (e.g., hand wipes and rinses) could be evaluated. Continuation of research of this nature could involve accumulating more surface area measurements to increase the existing database, gathering data from different populations, collecting variations of the current hand configurations, devising methods for three-dimensional plotting of the resulting contamination on the skin surface, and validating the modeled nonuniform loading on the skin with more sophisticated dermal exposure measurement techniques.

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